MEscope Application Note 46

FEA Model Updating

The steps in this Application Note can be carried out using any MEscope package that includes the **VES-4000 Modal Analysis & VES-8000 Finite Element Analysis** options. Without those options, you can still carry out the steps in this App Note using the **AppNote46** project file. These steps might also require MEscope software with ***a more recent release date***.

APP NOTE 46 PROJECT FILE

- To retrieve the Project for this App Note, **click here** to download **AppNote46.zip**

This Project contains ***numbered Hotkeys & Scripts*** for carrying out the steps of this App Note.

- ***Hold down*** the **Ctrl key** and ***click*** on a **Hotkey** to open its Script window

TARGETED FEA MODEL UPDATING

FEA Model Updating involves changing properties of an **FEA** model so that its **FEA** modes **more closely match** a set of **Target** modal parameters.

This is called **Targeted Model Updating** because with it you do the following

1. Use only those **FEA** elements to be updated on the **FEA** model by hiding all other **FEA** elements
2. Select **FEA & Target modal frequency pairs** and (optionally mode shape pairs) **to be closely matched to one another**
3. Select **FEA element properties** to be updating

FEA Model Updating uses the **SDM** method to calculate new **FEA** mode shapes due to changes in one or more selected **FEA** properties. The **SDM** method only requires the following,

1. The **FEA** mode shapes of the ***unmodified structure***
2. The **FEA** elements to be modified on the **FEA** model

EXHAUSTIVE SEARCH

FEA Model Updating calculates new mode shapes for all variations of **FEA** property values in a **user-defined solution space**. Then the solutions are ***ordered from best to worst*** based on the difference **between selected FEA & EMA target parameter pairs**.

Model Updating is done by using **SDM** to evaluate a potentially large number of solutions over a **user-defined solution space**. The exhaustive calculation of solutions guarantees that the best solution in the **user-defined solution space** will be found.

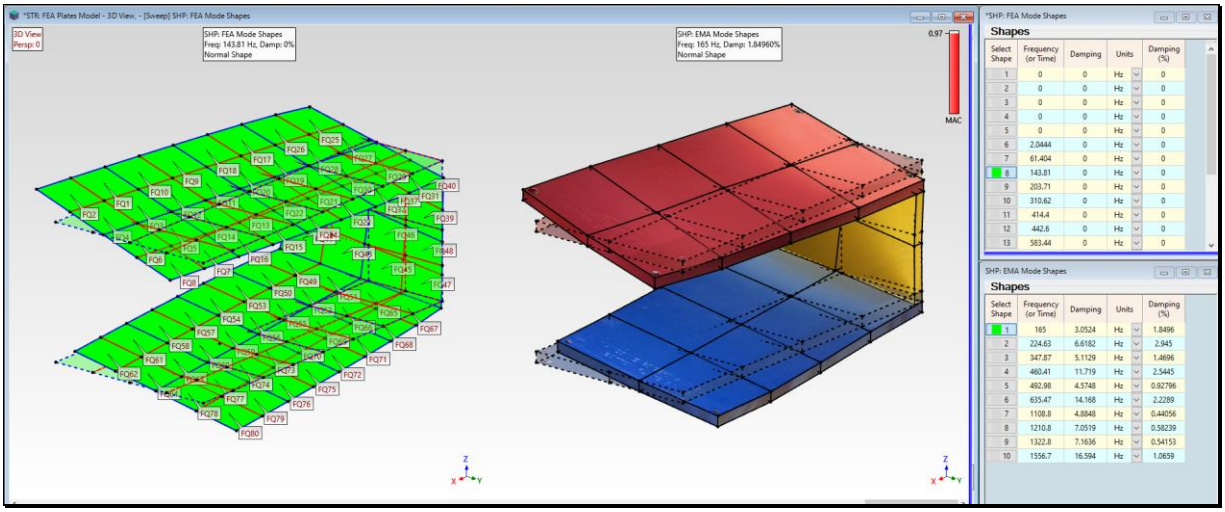
The **SDM** solutions are then ***ordered from best to worst.*** The **best solution** is the one that ***minimizes the difference*** between the **selected FEA & Target modal parameter pairs**.

The mode shapes of the **updated FEA model** can then be calculated using the **FEA** solver in **MEscope**, and the mode shapes saved in a Shape Table for comparison with the modes of the original model.

STEP 1 - FEA VERSUS EMA MODE SHAPES

- ***Press* Hotkey 1 FEA vs. EMA Mode Shapes**

To illustrate **FEA Model Updating**, **the thickness of the vertical plate** on the **FEA** model of the Jim Beam structure will be updated so that one of its **FEA** mode shape frequencies ***more closely matches*** one of its experimental **EMA** mode shape frequencies.



***FEA** Mode Shape #8 Side-by-Side with **EMA** Mode Shape #1.*

When **Hotkey 1 is *pressed***, sweep animation will begin from the Shape Table **SHP: FEA Mode Shapes** on the upper-right side in the **MEscope** display area. The **closest matching pair** of **FEA** & **EMA** mode shapes is displayed side-by-side as shown above.

Each **closest matching EMA** & **FEA** mode shape pair has the **Maximum MAC** (**M**odal **A**ssurance **C**riterion) value between the mode shape in one Shape Table and all other mode shapes in the other Shape Table.

MAC ➔ greater than 0.90 indicates a ***closely matching pair*** of mode shapes.

MAC ➔ less than 0.90 indicates that ***two mode shapes are different***.

- **Click** on a **Select Shape** button in either Shape Table ***on the right*** to display a pair of **closely matching** mode shapes

Each **EMA** mode shape **(1 through 10)** ***closely matches*** with one of the **FEA** mode shapes **(8 through 17)**.

NORMALIZED MODE SHAPES

Each **FEA** mode shape has **phases of 0 & 180-degrees**.

Mode shapes having shape components **with phases of 0 or 180 degrees** are called ***normal* mode shapes.**

Each **EMA** mode shape is a ***complex* mode shape**, with shape components that can have an ***arbitrarily phase*.**

To make the **EMA** mode shapes **correlate more closely** with the **FEA** mode shapes, the **EMA** mode shapes were ***normalized*** during animation.

Shape *normalization* retains the magnitude but changes the phase of each mode shape component to **0 or 180 degrees**.

MODAL FREQUENCY DIFFERENCES

The frequency of each **FEA** modal shape ***is significantly less*** than the frequency of each matching **EMA** mode shape. This means that the **stiffness** of the **FEA model *is less than the stiffness*** of the **Jim Beam test article**.

The **165 Hz EMA** mode shape and the **144 Hz FEA** mode shape have a **MAC ➔ 0.97**

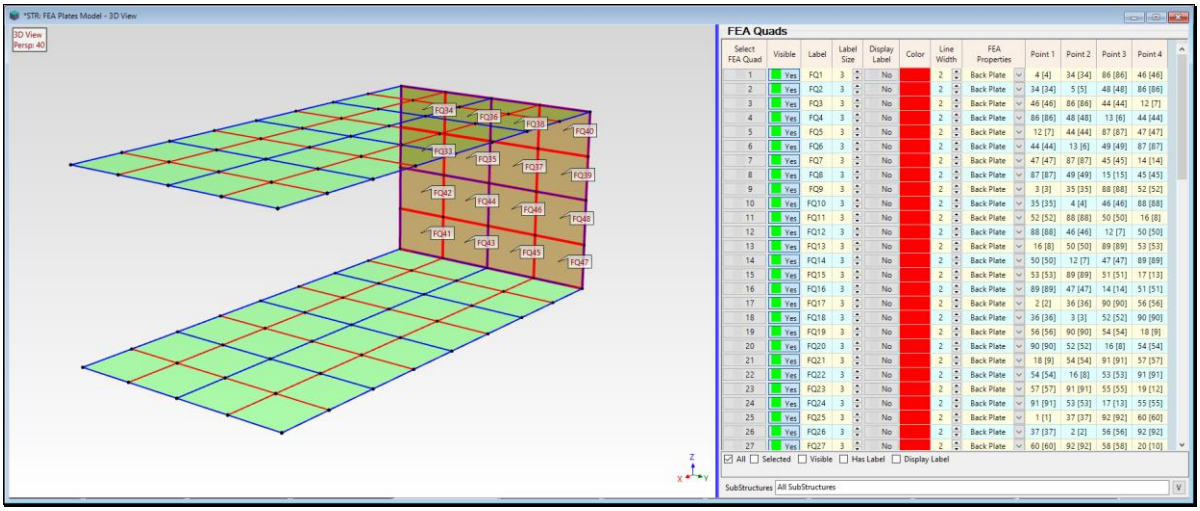
The **144 Hz FEA** mode shape is primarily a **torsional mode shape, *a twisting deflection*** of the back plate. Therefore, **increasing the thickness** of the back plate **should increase the frequency** of this **FEA** mode shape.

FEA Model Updating will be used to determine how much increase in the thickness of the back plate is necessary to make the frequency of this torsional mode shape ***more closely match*** the frequency of its ***closest matching*** **EMA** mode shape.

STEP 2 - SELECTING THE FEA QUADS ON THE BACK PLATE

- ***Press* Hotkey 2 Select FEA Quads on the Back Plate**

The **FEA** Quad elements on the back plate of the FEA Model ***are selected*** as shown below.



***FEA** Plate Model Showing 16 Selected **FEA** Quads on the Back Plate.*

The **FEA** Quads on the top & bottom plates are not selected and therefore will not be used during **FEA Model Updating**.

CHECKING ENGINEERING UNITS

To perform **FEA Model Updating**, the **STR: FEA Plates Model**, **SHP: FEA Mode Shapes** and **SHP: EMA Mode Shapes** files must have consistent engineering units.

- Check the **Units** column in the **M#s** spreadsheet in both the **SHP: FEA Mode Shapes** and **SHP: EMA Mode Shapes** windows to verify their mode shape units.
  - **(in/lbf-sec)** are typical English units for **UMM** mode shapes
  - **(mm/N-sec)** are typical Metric units for **UMM** mode shapes

To change engineering units in a Shape Table,

- ***Double click*** on the **Units** column heading in the **M#s** spreadsheet
- Type different units (for example, **mm/N-sec**) into the dialog box that opens
- ***Click*** on **OK** and **Yes** in the next dialog boxes to ***re-scale*** the shapes to the new engineering units

To check the engineering units of **STR: FEA Plates Model**,

- Execute **File | MEscope Options** in the **MEscope** window

- On the **Units** tab, select the **Mass, Force,** & **Length** units ***that are consistent with the units*** in the **SHP: FEA Mode Shapes** and **SHP: EMA Mode Shapes** files

In **English** Units, the dimensions of the Jim Beam are,

12 inches long by 6 inches wide by 4.75 inches high

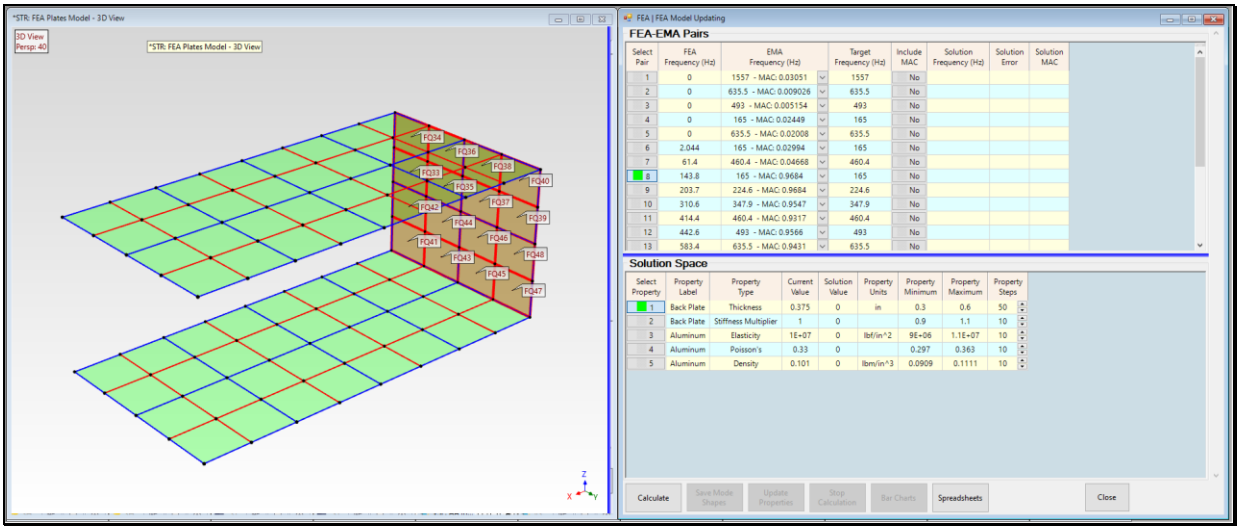
In **Metric** Units, the dimensions of the Jim Beam are,

304.8 millimeters long by 152.4 millimeters wide by 120.65 millimeters high

The **FEA** model, plus the **FEA** & **EMA** mode shapes are now ready to perform **FEA Model Updating**.

STEP 3 - FEA MODEL UPDATING

- ***Press* Hotkey 3 FEA Model Updating**



***FEA Model Updating** Window Before Solutions are Calculated.*

FEA Model Updating is done by calculating and ordering a large number of solutions over a **user-defined solution space**. The **FEA Model Updating** window ***on the right*** above contains two spreadsheets separated by a **horizontal blue splitter bar**.

UPPER SPREADSHEET

- The **Upper** spreadsheet is used for ***selecting* pairs** of **FEA mode shapes** and **Target mode shapes**.
- The modal frequency of each **FEA mode shape** is listed in the **FEA Frequency** column
- The modal frequency of each ***closest matching* EMA mode shape** is listed in the **EMA Frequency** column
- The **MAC** value for each mode shape pair is listed together with each **EMA Frequency**.
- Each **EMA** modal frequency is also listed in the **Target Frequency** column

Target frequencies can be **changed to desired values** by editing them in the **Target Frequency** column.

SOLUTION ERROR FUNCTION

All **FEA Model Updating** solutions are ***ordered from Best to Worst*** according to a **Solution Error Function**.

The **Solution Error Function** includes two terms for ***each selected* mode shape pair**,

The **percentage difference** between the **SDM Solution & Target frequency** for ***each selected* pair**

If **Yes** is selected in the **Include MAC** column, a second term (**1 - MAC**) is added to the **Solution Error Function.**

MAC is calculated between the **SDM Solution** and the **Target mode shape**.

When the **Calculate** button at the bottom of the **FEA Model Updating** window is pressed, the **thickness** of the **FEA Quads** on the back plate will be changed ***multiple times***, and the **SDM** solution for each thickness will be calculated and the solutions ordered so that the ***frequency of the former* 144 Hz FEA mode shape *more closely matches*** the **165 Hz Target** frequency.

- Make sure that **Shape Pair 8** is ***selected***, (the **144 Hz FEA mode shape** and the **165 Hz Target frequency)**

LOWER SPREADSHEET

The properties of all ***visible* FEA Objects** on the **FEA** model are listed in the **Lower Spreadsheet**. In this case, the properties of the **FEA Quad Plate Elements** on the back plate of the Jim Beam are listed.

Any properties listed in the **Lower Spreadsheet** can be updated to make the frequency (and optionally the mode shape) of the Solution ***more closely match*** the **Target** modal parameters.

SOLUTION SPACE

The **solution space** is defined in the **Lower Spreadsheet**.

A solution space should be defined **which includes each current property value**.

In this case the current plate thickness is **0.375 in.** In the **Lower Spreadsheet**,

- Enter **0.30** inches into the **Property Minimum** cell for the Back Plate **Thickness** Property
- Enter **0.60** inches into **the Property Maximum** cell for the Back Plate **Thickness** Property
- Enter **50** into the **Property Steps** cell for the Back Plate **Thickness** Property

The **Property Minimum, Property Maximum**, and **Property Steps** define the solution space for each property.

During the model updating calculations, ***all selected*** properties in the **Lower Spreadsheet** are varied between their **Property Minimum** & **Property Maximum** values using the number of **Property Steps**.

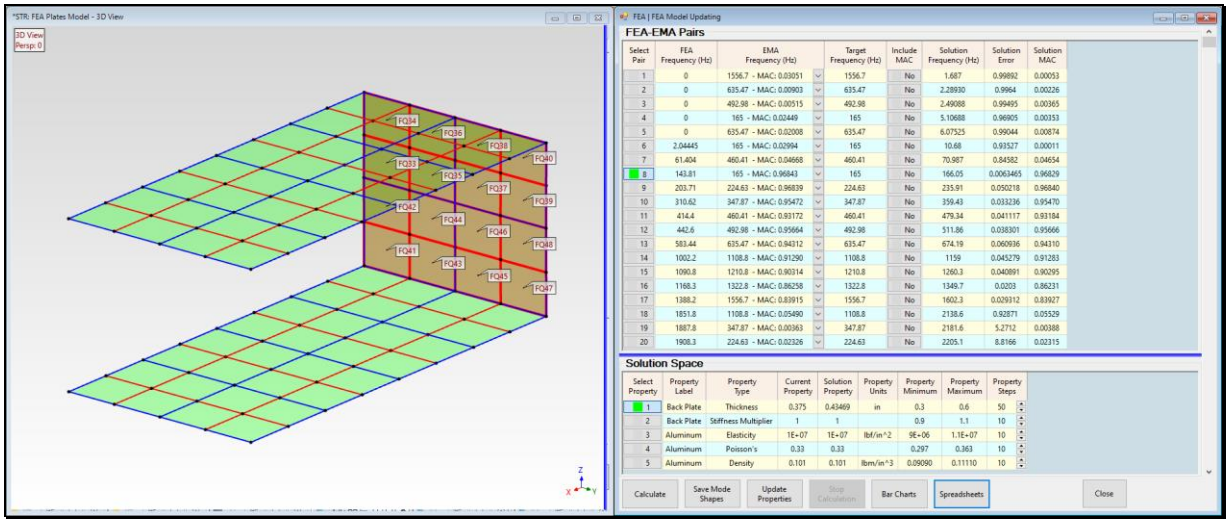
If no properties are ***selected***, then ***all properties*** in the **Lower Spreadsheet** are varied between their **Property Minimum** & **Property Maximum** values using the number of **Property Steps** for each property.

In this example, **50 SDM solutions** will be calculated using **50 different thicknesses, evenly spaced between 0.30 & 0.60 inches**.

CALCULATE SOLUTIONS

- Make sure that the **Back Plate Thickness** Property is ***selected*** in the **Lower** Spreadsheet
- ***Press*** the **Calculate** button on the bottom in the **FEA Model Updating** window

SDM solutions are calculated using **50 different plate thicknesses uniformly spaced between 0.30 & 0.60 inches**. When all solutions have been calculated and ordered from best to worst, the **Best** solution is displayed in the **FEA Model Updating** window as shown below.



***FEA Model Updating** Window After 50 SDM Solutions are Calculated.*

SOLUTION SCROLL BAR

After all the solutions are calculated, a **Solution scroll bar** is displayed ***on the right side*** of the **FEA Model Updating** window.

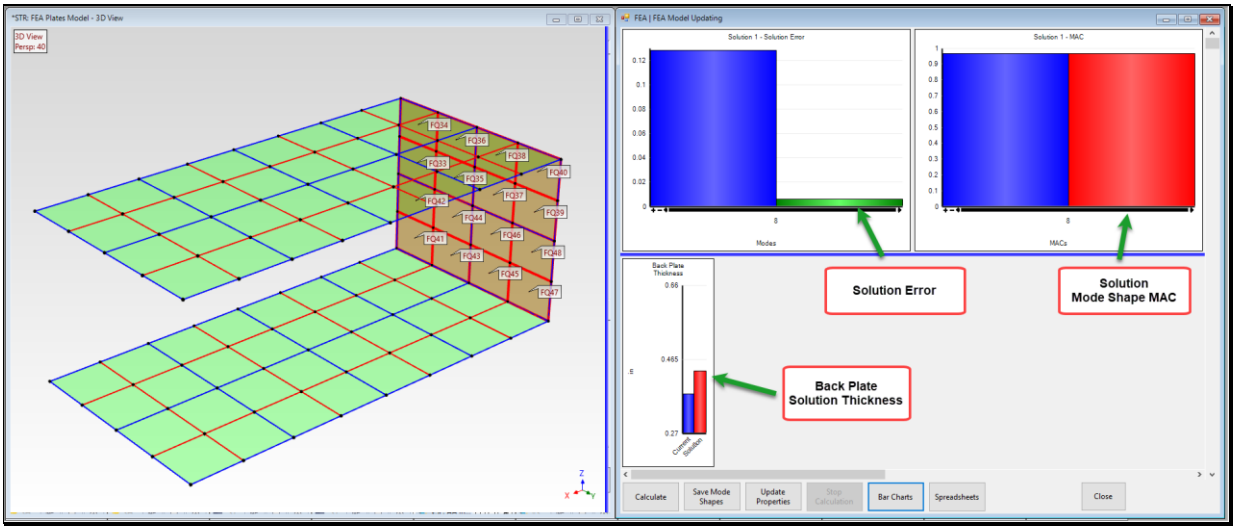
All 50 **SDM** solutions can be displayed using the **scroll bar** on the right side of the **Upper & Lower Spreadsheets**.

The modal parameters of the ***current* solution** are displayed in the **Upper Spreadsheet** and the values of the **FEA** properties for the ***current* solution** are displayed in the **Lower Spreadsheet**.

- Use the scroll bar to display each solution in both the **Upper & Lower Spreadsheets**
- The **Best** solution is displayed when the scroll is at the top of the scroll bar
- The **Worst** solution is displayed when the scroll is at the bottom of the scroll bar

SOLUTION BAR CHARTS

- ***Press* the Bar Charts button at the bottom of the FEA | Model Updating window**



FEA Model Updating Solution Bar Charts Display.

SOLUTION ERROR BAR CHART

The ***upper left*** **bar chart** displays **two Solution Error bars** for mode **shape pair 8**.

- The **blue bar** is the Solution Error between the current **FEA & Target** frequency
- The **green bar** is the Solution Error between the **Best Solution & Target** frequency
- ***Hover*** the mouse pointer over each bar to display its numerical value

The **blue** & **green bars** show that the **Solution Error** was ***significantly reduced*** by the **Best Solution** for mode **shape pair 8**.

MAC BAR CHART

The ***upper right*** **bar chart** displays **two MAC bars** for mode **shape pair 8**.

- The **blue bar** is the **MAC** between the **FEA mode shape** and its ***closest matching*** **EMA mode shape** before **SDM** solutions are calculated
- The **red bar** is the **MAC** between the **Solution mode shape** and the ***closest matching*** **EMA mode shape**
- ***Hover*** the mouse pointer over each bar to display its numerical value

The **blue** & red **MAC bars** indicate ***little change*** for the mode shape ***before & after*** the **SDM** solution, indicating that the mode shape ***was not affected*** by changing the thickness of the back plate.

LOWER BAR CHART

The ***lower*** **bar chart** displays two bars, one for the ***current*** **thickness** and one for the **SDM Solution thickness** of the ***selected*** **FEA property**.

- ***Hover*** the mouse pointer over each bar to display its numerical value

The back plate **thickness** for the **Best Solution ➔ 0.4347 in**. versus the ***current*** **thickness ➔ 0.375 in**.

SAVING THE UPDATED MODE SHAPES

When the **Save Mode Shapes** button is ***pressed*** on the bottom of the **FEA Model Updating** window, updated mode shapes are calculated using **SDM** and the current **FEA** Solution properties.

- ***Press*** the **Spreadsheets** button on the bottom of the FEA Model Updating window to display the **Upper & Lower Spreadsheets**
- ***Drag*** the **scroll bar** ***on the right side*** of the **FEA Model Updating** window ***to the top*** to display the Best Solution
- ***Press*** the **Save Mode Shapes** button on the bottom of the **FEA Model Updating** window to save the mode shapes for the **Best SDM Solution**

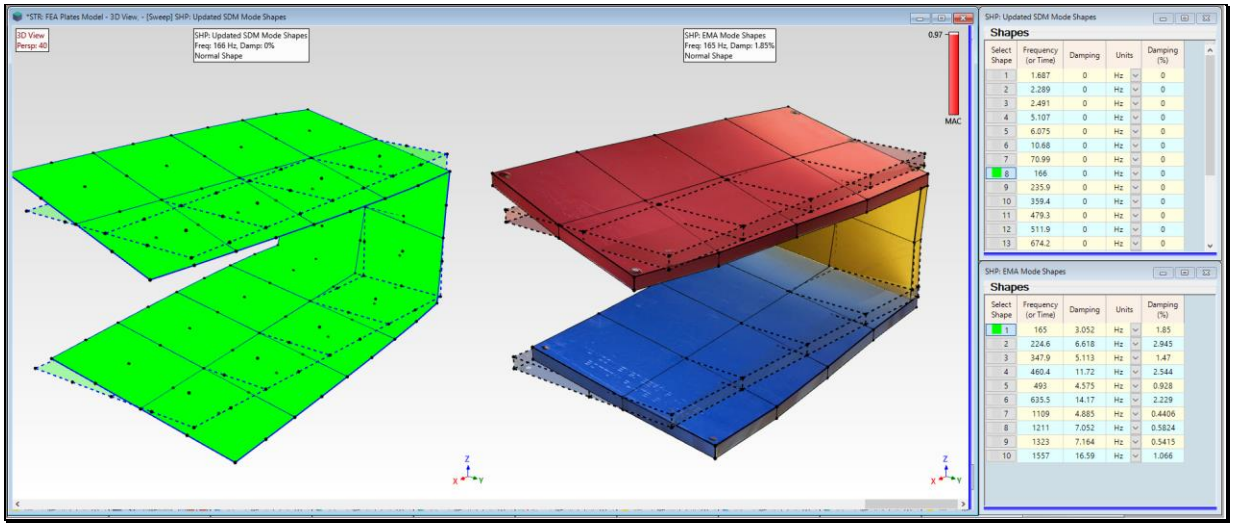
When the **Save Mode Shapes button is *pressed***, **SDM** uses the ***current*** **FEA** mode shapes of the Jim Beam together with the updated parameters (in this case, Back **thickness** of the back plate), and calculates new mode shapes for the Jim Beam. The new mode shapes are saved in the chosen Shape Table (in this case, **SHP: Updated SDM Mode Shapes**).

STEP 4 - UPDATED SDM VERSUS EMA MODE SHAPES

- ***Press*** **Hotkey 4 Updated SDM vs. EMA Mode Shapes**

When **Hotkey 4 is *pressed***, sweep animation will begin from the Shape Table **SHP: Updated SDM Mode Shapes** ***on the upper right***. Each ***closest matching*** pair of **SDM** & **EMA** mode shapes is displayed side-by-side as shown below.

Each closest matching **EMA** mode shape has a **Maximum MAC** (**M**odal **A**ssurance **C**riterion) value among all **EMA** mode shapes in **SHP: EMA Mode Shapes** with the ***currently selected*** **SDM** mode shape.



*Updated **SDM** Mode Shape #8 Side-by-Side with **EMA** Mode Shape #1.*

Comparisons of the **FEA**, **EMA**, and **SDM** mode shapes & frequencies before & after the thickness update of the back plate are shown in the table below.

The **SDM** modal frequencies for the FEA model with updated back plate thickness ➔ **0.435 inches *are much closer*** to the **EMA** frequencies and the **MAC** values ***remain the same*** for before & after the back plate thickness update.

Each **MAC** value indicates that each **SDM** mode shape (**8** through **17**) ***closely matches*** each **EMA mode shape** (**1** through **10**).

SDM Mode	EMA Mode	Current FEA Frequency Hz	EMA Frequency Hz	Updated SDM Frequency Hz	MAC Before SDM	MAC After SDM
8	**1**	143.8	**165**	**166**	**0.97**	**0.97**
9	**2**	203.7	**224.6**	**235.9**	**0.97**	**0.97**
10	**3**	310.6	**347.9**	**359.4**	**0.95**	**0.95**
11	**4**	414.4	**460.4**	**479.3**	**0.93**	**0.93**
12	**5**	442.6	**493**	**511.9**	**0.96**	**0.96**
13	**6**	583.4	**635.5**	**674.2**	**0.94**	**0.94**
14	**7**	1002	**1109**	**1159**	**0.91**	**0.91**
15	**8**	1091	**1211**	**1260**	**0.90**	**0.90**
16	**9**	1168	**1323**	**1350**	**0.86**	**0.86**
17	**10**	1388	**1557**	**1602**	**0.84**	**0.84**

STEP 5 - UPDATED FEA VERSUS SDM MODE SHAPES

As a final step, the mode shapes of the **FEA model** with the updated back plate **thickness ➔ 0.435 inches** will be calculated and compared in side-by-side animation with the mode shapes calculated by **SDM** using the same back plate thickness.

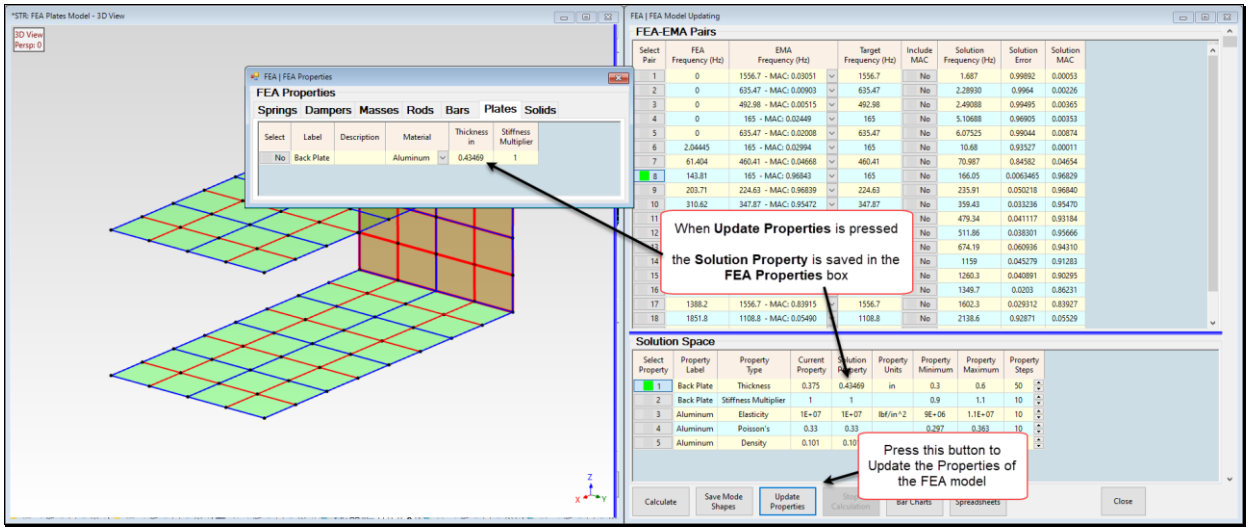
SAVING THE UPDATED PLATE THICKNESS SOLUTIONS

- ***Press* Hotkey 2 Select FEA Quads on the Back Plate *again***
- ***Press* Hotkey 3 FEA Model Updating *again***
- ***Press*** the **Calculate** button on the bottom in the **FEA Model Updating** window

When all solutions have been calculated and ordered from Best to Worst, the **Best** solution is displayed in the **FEA Model Updating** window as shown below.

- ***Press*** the **Update Properties** button on the bottom in the **FEA Model Updating** window

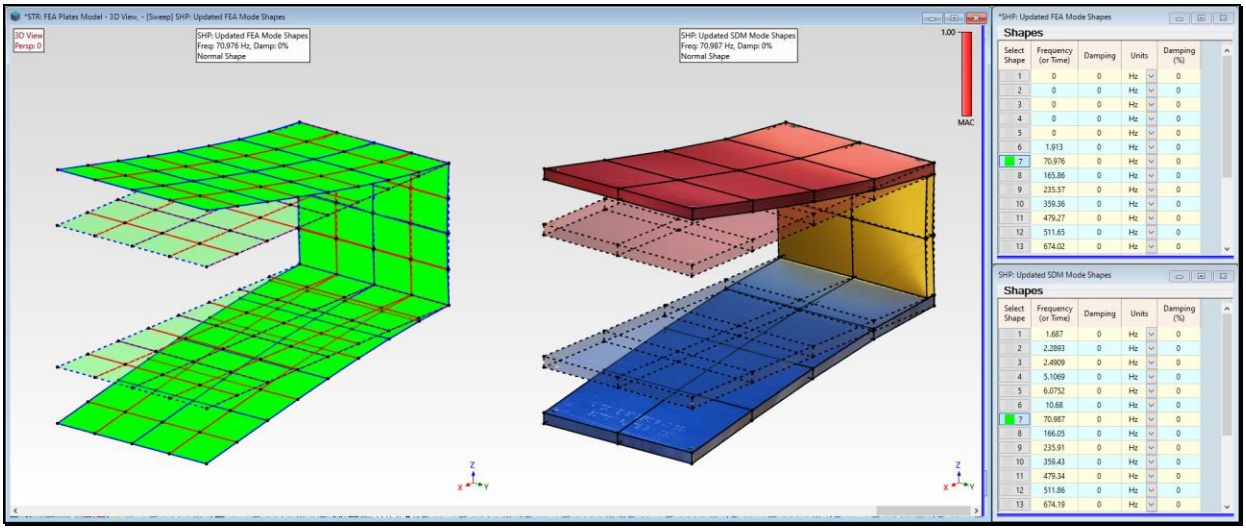
WARNING: The thickness property of **Back Plate** in the **FEA | FEA Properties** dialog box has now been replaced with the updated thickness property.



***FEA Model Updating** Window After Update Properties Button is Pressed.*

- ***Press* Hotkey 5 Updated FEA vs. SDM Mode Shapes**

New mode shapes will be calculated for the **Jim Beam FEA model**, and side-by-side sweep animation of the ***closest matching* pairs** of **FEA** & **SDM mode shapes** will begin, as shown below.



***FEA** Mode Shape Side-by-Side with Closest Matching **SDM** Mode Shape.*

Each ***closest matching* SDM mode** shape has a **Maximum MAC** value among all mode shapes in **SHP: Updated SDM Mode Shapes**. with the ***selected* FEA mode shape.**

Each **SDM mode shape** (**7** through **17**) ***closely matches*** (**MAC > 0.9**) with each updated **FEA** mode shape **(7 through 17)**.

The **frequency** of each **SDM mode shape** also ***closely matches*** the **frequency** of the same updated **FEA** mode shape with ***closely matching*** mode shape.

This final comparison of the mode shapes of the **updated FEA model** with the mode shapes calculated using **SDM** verifies the accuracy of **SDM**, which is the heart of **FEA Model Updating** in MEscope. Because it only requires a **Modal Model** to define the dynamics of the ***unmodified* structure**, **SDM** can be used to quickly examine many potential modifications to an **FEA** model by its use in **FEA Model Updated**.

STEP 6 - REVIEW STEPS

To review the steps of this App Note,

- ***Press* Hotkey 6 Review Steps**